

# THE LEACHING BEHAVIOR OF PERVIOUS MORTAR USED AS WATER FILTER IN RURAL AREAS

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**ABSTRACT:** Many people in rural areas use freshwater, including irrigation water for domestic purposes. The pervious mortar filter (PMF) is a modification of mortar and pervious concrete, designed as an alternative water filter to improve the natural water quality for domestic use. According to its physical characteristics (pore structure and geometry), pervious mortar can be a filter to reduce several types of pollutants in the water. On the other hand, based on its chemical characteristics, pervious mortar can be dissolved if passed by certain types of water for an extended period, called leaching. This study aims to determine the leachability of pervious mortar filters by identifying the influent and effluent concentration of calcium ion ( $\text{Ca}^{2+}$ ), hardness, pH, and total dissolved solids (TDS) in two types of water sources, i.e., pure water and irrigation water. This study analyzes the leachability of the filter by the filter column experiment method. The leaching is analyzed by the water's pH, TDS, calcium ion ( $\text{Ca}^{2+}$ ), and hardness concentration before and after the water is filtered by PMF. The filtered water for each specimen was 50 liters (L). 50 L of pure water showed increased pH, TDS values,  $\text{Ca}^{2+}$  concentration, and hardness in the effluent. The increase in pH, TDS,  $\text{Ca}^{2+}$ , and hardness concentration in the effluent with irrigation water was less than the increase of the same parameter in PMF through pure water.

*Keywords: Leaching, Pervious mortar, Water filter, Column experiment*

## 1. INTRODUCTION

The pervious concrete filter has the potential to provide clean water in flooded areas and rural areas where the water infrastructure is inadequately available. This kind of water filter has been patented by Majersky G. (2008) No. US 2008/0023404 A1 [1]. Pervious concrete comprises cement, aggregate, and water, allowing admixtures to be added for specific purposes [2,3]. Adding coarse aggregate or using large aggregates in the pervious concrete mixture could increase the porosity and permeability but reduce the compressive strength.

On the other hand, increasing the percentage of fine aggregate or using small aggregates will increase the compressive strength of pervious concrete and reduce the permeability of pervious concrete [3,4]. Based on its physical and hydraulic characteristics, pervious concrete can be used for many purposes, such as runoff water management, removal of runoff water pollutants, urban heat island mitigation, water treatment [1,5], wastewater treatment [6], plant growing media [7], pollutant adsorption (Phosphorous and Lead) [8,9], and others. The removal mechanisms usually used for these purposes are adsorption and filtration by the pervious concrete. Based on the filtration process, the filter or composite should have smaller pores to retain the small pollutants or particles in the pores.

Pervious mortar is a modification of mortar and pervious concrete in which the material type and the size range of sand are similar to mortar. Nevertheless, its utilization and hydraulic characteristics resemble pervious concrete. In contrast to the general use of mortar as a binder in building material, pervious mortar in this research is designed to be used as a water filter, called pervious mortar filter (PMF). This PMF consists of river sand (derived from Progo River, Yogyakarta, Indonesia), cement (Portland composite cement), and potable water. The river sand aggregate is ~ 0.425 – 0.850 mm in diameter. The specimens were cast with a diameter of 8.2 cm and a height of 5 cm, as seen in Fig. 1. This design made the filter lighter and easier to carry. By using small sand and certain mixture composition, the pore size will be smaller, the permeability will be lower than that of pervious concrete, and the permeability will be higher than that of conventional mortar. With these small pores and distinctive hydraulic characteristics, the smaller water pollutants (such as solids and biological contaminants) are effectively trapped within the filter's small pores. Hence, the authors employed a small, uniform aggregate to ensure optimal filtration performance. This kind of filter has also been studied by Taghizadeh (2007) [10], which was later named porous concrete, and Maadji (2016), which was then named a concrete filter [11]. The development of PMF technology as a water purification tool

was started by Triatmadja (2008) by using 1 – 2 mm sand as aggregate [11]. Comprehensive research using finer aggregates < 2 mm was then carried out by Kamulyan (2009) and Maadji (2017) [12,13].



Fig. 1 Pervious mortar filter with a diameter of 8.2 cm and a thickness of 5 cm.

The ability of PMF to reduce several types of pollutants is well known. The effectiveness of porous mortar in reducing turbidity ranges from 90% - 95% [11,12]. The pervious mortar filter with a sand aggregate of 0.15 – 0.30 mm, a sand cement ratio of 3, 4, 5, and 6, and a water-to-cement ratio of 0.4 was able to reduce the concentration of bacteria in water up to 98.71% or 2 logs of removal value (LRV). The PMF has a good pollutant retention capacity based on the physical characteristics (pore structure and geometry). On the other hand, based on its chemical characteristics, the pervious mortar or concrete can also be dissolved/ leached if passed by water for an extended period [14].

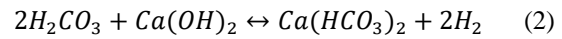
Leaching is one of the degradation phenomena that occur in concrete or cement-based composites. Leaching is one of the main factors that change the mechanical properties of cement-based composites [15–19]. The deterioration process known as "leaching" in the cement paste occurs due to contact with pure water or water with a low pH, which encourages the hydrolysis of hydrates [20]. This process is based on diffusion-dissolution, with diffusion fronts moving through the concrete. The diffusion of weathering agents from the surface into the bulk and the diffusion of dissolved products from the interior to the exterior are two ways hydrolysis reactions spread when an aggressive solution is present [18]. Dissolution is a process of carrying compounds/ions in concrete due to the leaching process due to the contact between water and portlandite ( $\text{Ca}(\text{OH})_2$ ). Portlandite is one of the crystals formed from a mixture of cement and water [17,21]. Leaching develops through a dissolution/precipitation process in concrete. The hydrolysis results in a significant increase in the porosity of the concrete or cement paste [22]. The chemical reactions in a

cement-based composite such as PMF can be seen in Eq. (1) – Eq. (4).

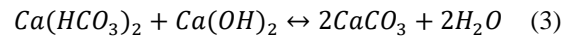
Formation of carbonic acid



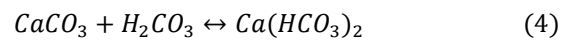
Dissolved calcium hydroxide



Calcium carbonate is formed.



Dissolved calcium carbonate



Several studies have investigated the effect of calcium ion ( $\text{Ca}^{2+}$ ) leaching on concrete's porosity and compressive strength or vice versa. Haga et al. (2005) investigated the effect of the porosity of ordinary hardened Portland cement on the leaching process. The larger the pore volume, the faster the portlandite contained in the sample is dissolved. Haga et al. (2005) concluded that the diffusion process controls the transport of dissolved substances/constituents. The main ingredients dissolved in hardened Ordinary Portland Cement (OPC) are portlandite and C-S-H gel [23].

Solpuker et al. (2014) studied the leaching potential and traced metal retention ability in pervious concrete. In the experiment with the column method, the water with a pH of 4.3 passes through pervious concrete. The results of the effluent water showed a high pH value (pH ~ 10). The conductivity decreased rapidly in the first 50 hours and then decreased slowly. In the early stages, trace metal leaching is very high but becomes low after 50 hours and gradually decreases with time [24].

A pervious mortar filter (PMF) is a modified version of mortar and pervious concrete designed to act as a water filter to provide clean water for domestic purposes. The PMF is intended for filtering surface water sources that possess specific initial water quality. Surface water sources, such as irrigation water, rivers, creeks, and lakes, are readily available in certain areas. However, their water quality is often unsuitable for direct use, particularly for drinking and domestic purposes. Nevertheless, people in rural areas still utilize irrigation water for activities like washing clothes, dishes, and other non-potable uses.

As the PMF is being proposed as a viable water filter in this area, it is crucial to examine its leaching potential. Numerous authors have investigated the impact of specific pH values on the leaching behavior of mortar, concrete, and

pervious concrete. However, there is a lack of studies on the leaching of pervious mortar filters when subjected to flowing surface water. Therefore, further research in this area is warranted. This study aims to determine the leachability potential of pervious mortar filter by identifying the influent and effluent concentration of calcium ion ( $\text{Ca}^{2+}$ ), hardness, pH, and total dissolved solids (TDS) in two types of water, i.e., pure water and irrigation water.

## 2. RESEARCH SIGNIFICANCE

Extensive studies have been conducted on the leaching behavior of pervious concrete, especially when specimens fully immersed in liquids with varying pH. However, in this study, we focused on observing the leaching behavior of PMF under the influence of flowing surface water rather than through total immersion. Additionally, our findings confirm that the leaching of PMF is influenced not only by the pH but also by the clarity of the water source, as determined by the initial total dissolved solids of water. These findings hold significant value for researchers and practitioners engaged in water and wastewater treatment.

## 3. METHODS AND MATERIALS

### 3.1 Specimen Preparation

The PMF is made from sand, cement, and water, without admixture or additive. The size of the natural sand used is 0.425 – 0.850 mm, and the type of cement used is Composite Portland Cement (PCC). Admixtures or other additives are not used in this PMF to prevent the risk of heavy metal leaching [25]. The chemical and physical characteristics of both sand and cement are given in Table 1. The sand-cement ratio is four, and the water-cement ratio is 0.4 by weight. The mixture design of PMF prepared for this study is presented in Table 2.

The mixing process was conducted using a Hobart mortar mixer. This process is a modification of the production process of porous concrete by Park and Tia (2004) [26]. Modifications were made because the grain size of the sand used was different. This study used a much smaller sand size. Modifications were carried out on the mixing and stirring time of 2 minutes. The mixing and stirring process began by entering half of the sand and half of the cement into the mixer and stirring for 2 minutes, then adding the remaining sand and cement and stirring for 2 minutes. After all the ingredients are mixed and look homogeneous, add water and stir for 2 minutes.

The ready-casted PMF mixture was cast on a 3-inch PVC pipe with a height of 5 cm. The casting process was carried out on a vibrating table. The PMF casting process was modified from the casting process in the previous research by Maadji (2016) [13] and by a preliminary experiment conducted before this study.

Table 1 Chemical and physical characteristics of sand and cement

Sand (Progo Sand)		Cement (PCC)	
Element	Value	Element	Value
SiO <sub>2</sub> (mass%)	39.10	SiO <sub>2</sub> (mass%)	18.52
P <sub>2</sub> O <sub>5</sub> (mass%)	3.768	P <sub>2</sub> O <sub>5</sub> (mass%)	6.65
SO <sub>3</sub> (mass%)	0.509	SO <sub>3</sub> (mass%)	2.051
CaO (mass%)	9.958	CaO (mass%)	67.53
TiO <sub>2</sub> (mass%)	4.351	TiO <sub>2</sub> (mass%)	0.633
MnO (mass%)	0.532	MnO (mass%)	0.121
Fe <sub>2</sub> O <sub>3</sub> (mass%)	31.70	Fe <sub>2</sub> O <sub>3</sub> (mass%)	4.23
CuO (mg/kg)	654.8	CuO (mg/kg)	513
ZnO (mg/kg)	660	ZnO (mg/kg)	359
Rb <sub>2</sub> O (mg/kg)	187.6	Rb <sub>2</sub> O (mg/kg)	73.7
SrO (mass%)	0.199	SrO (mg/kg)	519
BaO (mass%)	0.102	BaO (mg/kg)	382
Al <sub>2</sub> O <sub>3</sub> (mass%)	7.65	As <sub>2</sub> O <sub>3</sub> (mg/kg)	75.9
K <sub>2</sub> O (mass%)	1.981	NiO (mg/kg)	684
Density (kg/m <sup>3</sup> )	2,480	Density (kg/m <sup>3</sup> )	2,960

A mixture of  $\pm 200$  grams of PMF was put into the mold. The ballast (stainless steel weighing 225 grams) was placed on top of the mixture and started to 10-speed vibrate for 1 minute. Continue for every  $\pm 200$  grams of the following mixture of materials until it slightly exceeds the height of the mold (approximately three times filling). Trim the excess height of the mixture with a leveling ruler. The mold filled with the mixture is turned over, put weight on it, and vibrated again for 1 minute. The final stage of reversal (to the initial position of the mold) was carried out and vibrated again for 30 seconds by placing a leveling board on the surface of the pervious concrete mixture.

After casting, the specimen was dried for 24 hours at room temperature ( $\pm 26$  °C). After that, the specimens were cured with humid cotton covering for 90 days. After reaching the age of 90 days, the PMF was ready to be used as a filter.

### 3.2 Leachability Test

The increase in pH value in the effluent (filtered water) investigated the occurrence of leaching in the PMF, as well as the levels of total

dissolved solids (TDS), calcium ions ( $\text{Ca}^{2+}$ ), and hardness. The leaching level of a specimen depends on the type of water (pH, turbidity, other water quality concentration) that is infiltrated into the specimen. The water used in this study as influent water is pure and surface water (from irrigation). The irrigation water, originated from Opak River at Kalitirto Village, Yogyakarta Province (Coordinate: -7.785111, 110.456375), was chosen where some villagers use this water source for domestic uses, such as washing clothes and dishes. At the same time, pure water was used as a control in this study. These two types of water are significantly different regarding turbidity, pH, and TDS, as seen in Table 3.

Table 2 The pervious mortar mixture design

Criteria	Value and unit
Sand size	0.425 – 0.850 mm
Cement type	Portland composite cement (PCC)
Sand-cement ratio (M)	4
Water-cement ratio	0.4
Diameter of specimen	8.2 cm (cast in a 3-inch PVC pipe)
Thickness of specimen	5 cm
Porosity	15 %
Permeability	0.058 – 0.064cm/s
Curing type	Humid cotton covering
Curing time	90 days

This study analyzed the leachability potential of the PMF with the column experiment method. In this experiment, as much as 1 L of raw water flowed into the filter. The water before and after being put into the filter column was tested for pH, TDS,  $\text{Ca}^{2+}$ , and hardness. The total of raw water entered into each specimen was 50 L. Every 10 L, the filtered water was tested for  $\text{Ca}^{2+}$  and hardness concentration. The schematic of the laboratory experiment can be seen in Fig. 2, and the test variable is presented in Table 3.

#### 4. RESULTS AND DISCUSSION

##### 4.1 X-Ray Diffraction of PMF

X-Ray diffraction is used to characterize the pervious mortar composition. The results showed the presence of minerals from the mixture of Progo Sand and PCC cement used, as seen in Fig. 3. These minerals are calcite (21%), Albite, calcian (57.3%), and Diopside (13.8%). This dominant Albite mineral comes from the Albite mineral (79.4%) in the Progo Sand as aggregate from granite rocks. The Calcite mineral with a composition of 21%, which is formed in this composite, comes from the PCC cement, which produces hydration products in the form of calcite (35.7%), Portlandite (23.9%), Aragonite (8.3%),

Albite calcian (14%), and Larnite (14.3%).

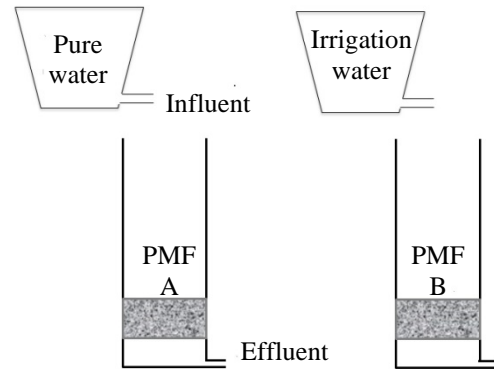


Fig. 2 A laboratory scale of PMF experiment set up

Table 3 The variables used in the experiment

Experiment content	Variables
Influent water	Pure water (A) and irrigation water (B)
Influent total volume	50 L for each specimen
Test items	pH value & TDS (every 1 L of influent)
	Calcium & Hardness (every 10 L of influent)
Operation mode	Falling head operation
Initial water quality of Pure water	pH 7, TDS 0 ppm, $\text{Ca}^{2+}$ 0.4 mg/L, hardness 2.5 mg/L, Turbidity 0 NTU
Initial water quality of Irrigation water	pH 7.75, TDS 98 ppm, $\text{Ca}^{2+}$ 16.08 mg/L, hardness 68.34 mg/L, Turbidity 20 NTU

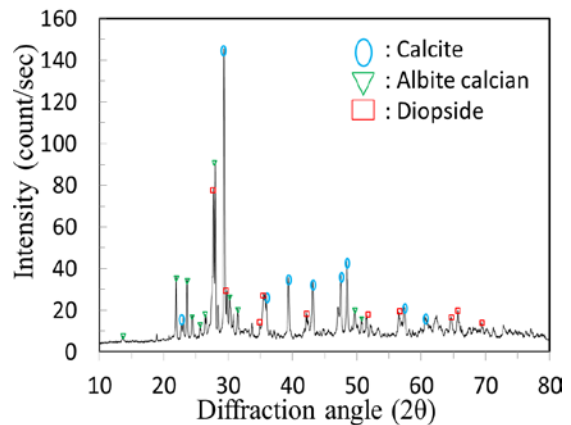


Fig. 3 X-Ray Diffraction of pervious mortar with sand cement ratio (M) 4

The mineral Calcite or Calcium Carbonate ( $\text{CaCO}_3$ ), which is formed in this composite, as also supported by the scanning electron microscopy (SEM) analysis in Fig. 4, is the result of a chemical reaction process between Calcium Bicarbonate ( $\text{Ca}(\text{HCO}_3)_2$ ) and Calcium Hydroxide ( $\text{Ca}(\text{OH})_2$ ) as can be seen in Eq. (3). This Calcium Carbonate then reacts with the Carbonic Acid (Eq.

(1)) produces Calcium Bicarbonate ( $\text{Ca}(\text{HCO}_3)_2$ ). Calcium Bicarbonate is in the aqueous phase consisting of calcium ( $\text{Ca}^{2+}$ ), bicarbonate ( $\text{HCO}_3^-$ ), carbonate ( $\text{CO}_3^{2-}$ ) ions, and dissolved carbon dioxide ( $\text{CO}_2$ ).

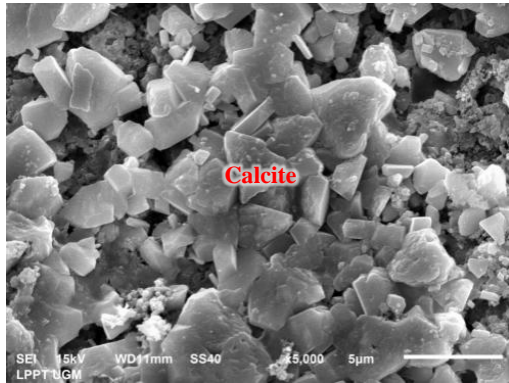


Fig. 4 Scanning electron microscopy (SEM) of pervious mortar with sand cement ratio (M) 4

Calcite within the PMF undergoes leaching as water infiltrates, dissolving  $\text{Ca}^{2+}$  into the water. Consequently, the pH, as well as the concentrations of  $\text{Ca}^{2+}$  and hardness, increase in the effluent. This pattern has also been observed in other studies, where the leaching of calcium content in pervious mortar led to an elevation in pH within the effluent [15,26].

#### 4.2 Effect of the Influent's Water on Leaching

The leaching potential of two PMF specimens was assessed using two types of water: pure water and irrigation water. Each specimen underwent 50 cycles of water flow, each consisting of 1 L, resulting in a total of 50 L passing through the specimens throughout the experiment. The leaching potential of these specimens in the two types of water was examined by measuring the concentration of several key water quality parameters, including pH, TDS,  $\text{Ca}^{2+}$ , and hardness, in both the influent and effluent. It was observed that the dissolution of alkaline and portlandite from the pervious concrete specimens led to an increase in the pH value and turbidity of the effluent water [23,27].

The PMF system, when supplied with pure water, exhibits an effluent pH ranging from 8.54 to 9.33, starting from an initial pH value of 7, as shown in Fig. 5. Conversely, the influent pH for irrigation water is 7.75, and the corresponding effluent pH ranges from 7.09 to 8.62. Throughout the dissolving process, solid particles dissolve and are carried by water to the PMF outlet. The dominant solid particles that dissolve and are carried by the water are cations, specifically

calcium ions ( $\text{Ca}^{2+}$ ). The high pH value observed in the effluent resulting from pure water input suggests that the water carried to the PMF outlet contains dissolved cations, consequently leading to an elevated pH level, indicating alkalinity.

The influent TDS concentration of pure water is 0 ppm, while it ranges from 9 to 18 ppm in the effluent. In contrast, the initial TDS concentration of irrigation water is 98 ppm, increasing to 98 to 107 ppm in the effluents, as seen in Fig.6.

Greater dissolution intensity is observed in the PMF system with pure water compared to irrigation water, as evidenced by the rising pH values and TDS concentrations, as depicted in Fig. 7. This graph illustrates the disparity between the increasing TDS concentration and pH levels in pure and irrigation water. The increase in TDS concentration from pure water is higher than from irrigation water influent.

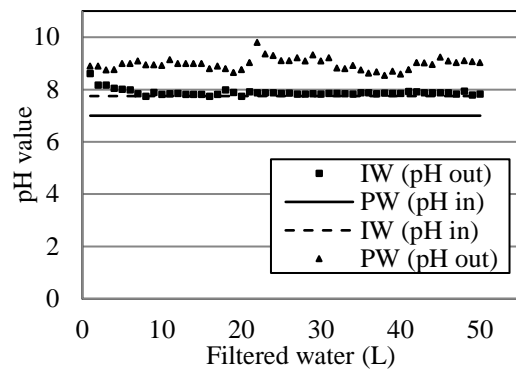


Fig. 5 The pH value of PMF for two types of water

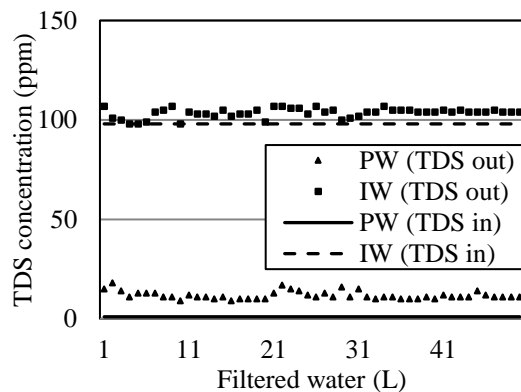


Fig. 6 The TDS concentration of PMF for two types of water

The graph (Fig. 7) illustrates the variations in TDS concentration in PMF systems using pure and irrigation water. In PMF with pure water, the TDS concentration increases within the range of 9 to 18 ppm, while in irrigation water, the increase ranges from 0 to 9 ppm. Similarly, the pH values also experience an increase. In PMF with pure water,

the pH value increases by 1.6 to 2.81, whereas in PMF with irrigation water, the increase ranges from 0 to 0.87.

These findings indicate that the rise in TDS concentration and pH value is more pronounced in PMF systems that utilize pure water than irrigation water ones. Although the initial pH values are similar for pure water (7) and irrigation water (7.75), the increase in pH concentration differs significantly between the two water sources. Particularly, the PMF system with pure water exhibits a greater increase in pH compared to the system with irrigation water. Additionally, it is crucial to highlight the substantial disparity in initial TDS concentration between pure water (0 ppm) and irrigation water (98 ppm).

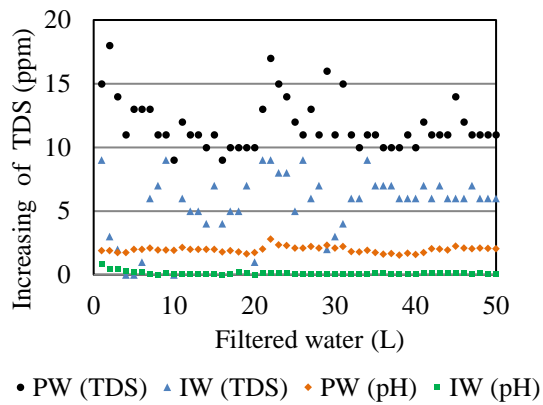


Fig. 7 The increasing concentration of TDS and pH in two types of influents

However, the difference in influent concentration significantly affects the final concentration of TDS. The increase in TDS concentration in the effluent demonstrates an inverse relationship, where a smaller TDS concentration in the influent results in a higher concentration increase, and vice versa. These findings conclude that the solubility of calcium ion ( $\text{Ca}^{2+}$ ) in cement-based composites is not solely determined by the water's pH but also by the clarity or purity of the water, as indicated by its TDS value. The purer the water, the greater the solubility level. This phenomenon arises due to the chemical reaction during the leaching process of cement hydration products in PMF when exposed to pure water, considering the differences in solid concentration and pH value between pure water and pore water inside PMF. Due to these conditions, pure water can dissolve more cement-based solid particles, leading to a high TDS value in the effluent. The chemical reactions that take place when water ( $\text{H}_2\text{O}$ ) infiltrates the cement-based composite can be observed in Eq. (1) to Eq. (4).

The graph displayed in Fig. 8 indicates that the presence of  $\text{Ca}^{2+}$  and hardness concentrations derived from dissolved calcite causes the elevated TDS and pH values observed in the effluent when pure water is used as the influent in PMF. The primary solid particles dissolved and carried by the water are cations, specifically calcium ions ( $\text{Ca}^{2+}$ ) or lime. Significantly greater leaching intensity is observed in PMF systems with pure water influent, as demonstrated by the effluent  $\text{Ca}^{2+}$  concentration ranging from 1.4 to 2.6 mg/L (with an initial  $\text{Ca}^{2+}$  concentration of 0.4 mg/L). Furthermore, the trend is consistent for hardness concentration in the effluent, which ranges from 4.5 to 8 mg/L (with an initial hardness of 2.5 mg/L), as depicted in Fig. 8.

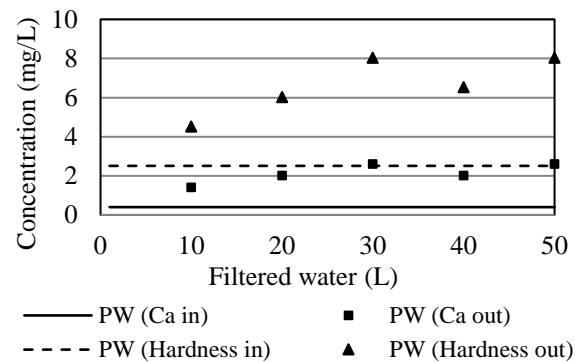


Fig. 8 The concentration of  $\text{Ca}^{2+}$  and hardness in pure water

The initial  $\text{Ca}^{2+}$  concentration of irrigation water was 16.08 mg/L, and the effluent concentration ranged from 12.86 to 19.3 mg/L, as shown in Fig. 9. Moreover, the initial hardness was 68.34 mg/L, and the effluent concentration ranged from 68.34 to 76.38 mg/L.

The elements of  $\text{Ca}^{2+}$  and hardness in the PMF effluent are derived from the results of the chemical process of concrete as presented in Eq. (1) – Eq. (2). At the PMF curing age of 90 days, the solubility level of calcium ion becomes smaller and is affected by the type of water that will be filtered through the PMF. Pure water contains water ( $\text{H}_2\text{O}$ ) which is purer than the water found in irrigation water. With contact with the atmosphere,  $\text{CO}_2$  will easily enter and react with  $\text{H}_2\text{O}$  to produce carbonic acid.

The leaching process of the hydration product by irrigation water was not optimal. This condition was due to impurities in the influent, thereby blocking the chemical reaction between the hydrated cement product and water. It was shown by the low calcium ion and hardness concentration increment in the PMF effluent, as seen in Fig. 8. The results of this study indicate that the leaching intensity of PMF is lower for irrigation water influent. It is understandable because PMF is a

cement-based composite with a pH value above 12.5, which is very alkaline. According to that characteristic, the material composed of cement will be easily damaged if attacked by pure and acidic water [18,20]. Contact between specimens composed of hydrated cement (pH above 12.5) with a low mineral and/or low pH water causes hydrolytic decomposition, which disrupts the balance of the cement matrix and degrades, thus dissolving compounds in the hydrated cement [20].

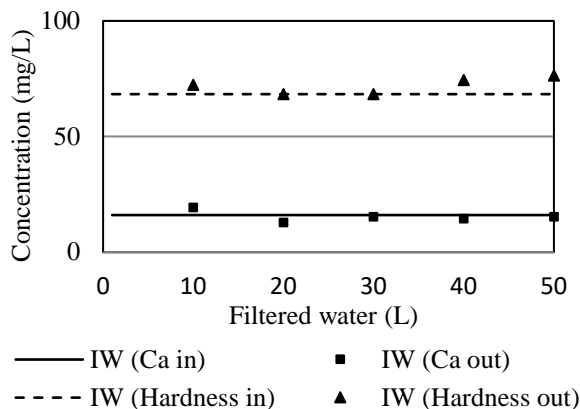


Fig. 9 The concentration of Ca<sup>2+</sup> and hardness in irrigation water

## 5. CONCLUSION

The effluent from the PMF exhibited an increase in pH and TDS values when subjected to the passage of 50 L of pure water. Pure water, which enters the specimen, has a higher capacity to dissolve Calcium Bicarbonate (Ca(HCO<sub>3</sub>)<sub>2</sub>) containing calcium ion (Ca<sup>2+</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>), carbonate (CO<sub>3</sub><sup>2-</sup>) ions, and dissolved carbon dioxide (CO<sub>2</sub>) compared to the irrigation water. As a result, it carries dissolved ions out of the specimen through diffusion and convection processes. Moreover, the concentration of Ca<sup>2+</sup> and water hardness in the effluent water exhibited an increase subsequent to the passage of pure water through the PMF. The results showed that increased pH, TDS, Ca<sup>2+</sup>, and effluent hardness concentration were more significant when using pure water instead of irrigation water. These findings indicate that the leaching potential of PMF with pure water is higher than that with irrigation water.

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## REFERENCES

- [1] Majersky G., Concrete Filtering Systems and Methods, United States Patent Application Publication, Denver, 2008, US 2008/0023404 A1, pp.1–25, <https://www.freepatentsonline.com/20080023404.pdf>.
- [2] Ramkrishnan R., Abilash B., Trivedi M., Varsha P., Varun P., and Vishanth S., Effect of Mineral Admixtures on Pervious Concrete, *Materials Today: Proceedings*, Vol. 5, No. 11, 2018, pp. 24014–24023, DOI:10.1016/j.matpr.2018.10.194.
- [3] Pereira da Costa F.B., Haselbach L.M., and da Silva Filho L.C.P., Pervious Concrete for Desired Porosity: Influence of W/C Ratio and a Rheology-Modifying Admixture, *Construction and Building Materials*, Vol. 268, 121084, 2021, DOI:10.1016/j.conbuildmat.2020.121084.
- [4] Neamitha M. and Supraja T.M., Influence of Water Cement Ratio and The Size of Aggregate on The Properties of Pervious Concrete, *International Refereed Journal of Engineering and Science (IRJES)*, Vol. 6, No. 4, 2017, pp. 09–16.
- [5] Vijayalakshmi R., Recent Studies on the Properties of Pervious Concrete; A Sustainable Solution for Pavements and Water Treatment, *Civil Environmental Engineering Reports*, Vol. 31, No. 3, 2021, pp. 54–84. DOI:10.2478/ceer-2021-0034.
- [6] Aboelkheir M.G., Pal K., Cardoso V.A., Celestino R., Yoshikawa N.K., and Resende M.M., Influence of Concrete Mixer Washing Waste Water on the Chemical and Mechanical Properties of Mortars, *Journal of Molecular Structure*, Vol. 1232, 2021, DOI:10.1016/j.molstruc.2021.130003
- [7] Yamaya K., Oyake Y., Suenaga Y., and Yoshida H., Study on Physical Properties and Grass Growth Capacity of Porous Concrete, *International Journal of GEOMATE*, Vol. 22, No. 91, 2022, pp. 08-13, DOI:10.21660/2022.91.7553.
- [8] Wu F., Yu Q., and Brouwers H.J.H., Phosphorus Removal Enhancement by Porous Adsorptive Mortar using Miscanthus and Steel Slag for Highly Adsorptive Concrete, *Construction and Building Materials*, Vol. 295, 123686, 2021, DOI:10.1016/j.conbuildmat.2021.123686.
- [9] Krishnan C.R., Santhanam M., Kumar M., and Rangarajan M., Iron Oxide-Modified Pervious Concrete Filter for Lead Removal from Wastewater, *Environmental Technology*

- and Innovation, Vol. 28, 102681, 2022, DOI:10.1016/j.eti.2022.102681.
- [10] Taghizadeh M.M., Torabian A., Borghei M., and Hassani A.H., A Study of Feasibility for Water Purification using Vertical Porous Concrete Filter. *International Journal of Environmental Science and Technology*, Vol. 4, No. 4, 2007, pp. 505-512, DOI:10.1007/BF03325987.
- [11] Triatmadja R., *Kajian Awal Prospek Filter Beton Pasir sebagai Teknologi Tepat Filtrasi Air Bersih*, Seminar Nasional Teknologi Tepat Guna Penanganan Sarana Prasarana di Indonesia, 2008, pp. 1-9.
- [12] Kamulyan B., Nurrochmad F., Triatmadja R., and Sunjoto S., Capacity of Concrete Sand Filter to Treat High Turbid Water, *International Conference on Sustainable Development for Water and Wastewater Treatment*, Yogyakarta, Indonesia, 2009.
- [13] Maadji R., Triatmadja R, Nurrochmad F, Sunjoto. The Concrete Filter Mix Design for Water Treatment. *Proceedings of the Second IAHS Panta Rhei International Conference on Water System Knowledge Innovation and its Practices in Developing Countries*. 2017.
- [14] Hartwich P. and Vollpracht A., Influence of Leachate Composition on the Leaching Behaviour of Concrete, *Cement and Concrete Research*. Vol. 100, 2017, pp. 423-434, DOI:10.1016/j.cemconres.2017.07.002.
- [15] Vadas T.M., Smith M., and Luan H., Leaching and Retention of Dissolved Metals in Particulate Loaded Pervious Concrete Columns, *Journal of Environmental Management*, Vol. 190, 2017, pp. 1-8, DOI:10.1016/j.jenvman.2016.12.047.
- [16] Ueno T., Yanaka A., Okazaki S., Matsumoto N., and Yoshida H., Physical Property and Heavy Metal Leaching Behavior of Concrete Mixed With Woody Ash, *International Journal of GEOMATE*, Vol. 24, 2023, pp. 77-84, DOI:10.21660/2023.102.s8530.
- [17] Liang T., Zhou J., and Wu Q., Experimental Investigation on Leaching Behavior of Ultra-High Performance Concrete Submitted to a Flow Environment, *Construction and Building Materials*, Vol. 372, 130843 2023, DOI:10.1016/j.conbuildmat.2023.130843.
- [18] Overmann S., Lin X., and Vollpracht A., Investigations on the Leaching Behavior of Fresh Concrete – A Review, *Construction and Building Materials*, Vol. 272, 121390, 2021, DOI:10.1016/j.conbuildmat.2020.121390.
- [19] Wang Y., Tao M., Feng D., Jiao Y., Niu Y., and Wang Z., Effect of Leaching Behavior on the Geometric and Hydraulic Characteristics of Concrete Fracture, *Materials*, Vol. 15, 4584, 2022, DOI:10.3390/ma15134584.
- [20] Youssari F.Z., Taleb O., and Benosman A.S., Towards Understanding the Behavior of Fiber-Reinforced Concrete in Aggressive Environments: Acid Attacks and Leaching, *Construction and Building Materials*, Vol. 368, 130444, 2023, DOI:10.1016/j.conbuildmat.2023.130444.
- [21] Kim G.M., Jang J.G., Khalid H.R., and Lee H.K., Water Purification Characteristics of Pervious Concrete Fabricated with CSA Cement and Bottom Ash Aggregates, *Construction and Building Materials*, Vol. 136, 2017, pp. 1-8, DOI:10.1016/j.conbuildmat.2017.01.020.
- [22] Marinoni N., Pavese A., Voltolini M., and Merlini M., Long-Term Leaching Test in Concretes: An X-ray Powder Diffraction Study, *Cement and Concrete Composites*, Vol. 30, No. 8, 2008, pp. 700-705, DOI:10.1016/j.cemconcomp.2008.05.004.
- [23] Haga K., Sutou S., Hironaga M., Tanaka S., and Nagasaki S., Effects of Porosity on Leaching of Ca from Hardened Ordinary Portland Cement Paste, *Cement and Concrete Research*, Vol. 35, No. 9, 2005, pp. 1764-1775, DOI:10.1016/j.cemconres.2004.06.034.
- [24] Solpuker U., Sheets J., Kim Y., and Schwartz F.W., Leaching Potential of Pervious Concrete and Immobilization of Cu, Pb and Zn using Pervious Concrete, *Journal of Contamination Hydrology*, Vol. 161, 2014, 35-48, DOI:10.1016/j.jconhyd.2014.03.002.
- [25] Wang D., Wang Q., Cui Y., and Pang L., Assessing Heavy-Metal Leaching Risk in Cement-Industrial Slag Composite Pastes using a Mechanism-Based Thermodynamic Approach, *Cement and Concrete Composites*, Vol. 140, 105074, 2023, DOI:10.1016/j.cemconcomp.2023.105074.
- [26] Park S.B. and Tia M., An Experimental Study on the Water-Purification Properties of Porous Concrete, *Cement and Concrete Research*, Vol. 34, 2004, pp. 177-184. doi:10.1016/S0008-8846(03)00223-0
- [27] Muthu M., Santhanam M., and Kumar M., Pb Removal in Pervious Concrete Filter: Effects of Accelerated Carbonation and Hydraulic Retention Time, *Construction and Building Materials*, Vol. 174, 2018, pp. 224–232, DOI:10.1016/j.conbuildmat.2018.04.116.